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RESULTS FROM HiRes AND OBSERVATION OF THE GZK CUTOFF*

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HiRes measurements of the highest energy cosmic rays lead to the observation of the GZK cutoff. HiRes consequently puts new limits on the resulting flux of cosmogenic neutrinos.

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1. Introduction

HiRes is an air fluorescence experiment for the highest energy cosmic rays (CR). Extensive air showers (EAS) of mostly photons, electrons, and positrons are propagating through the atmosphere dissipating the energy originally carried by the CR particle that interacted in the upper atmosphere. They excite an afterglow of fast-decaying nitrogen fluorescence that traces the shower and the evolution of its charged particle content across the night sky. On moonless nights fluorescence detectors image this afterglow and therewith trace the EAS evolution throughout the atmosphere in a calorimetric manner.

The HiRes experiment uses two fluorescence detector sites that are located on hilltops 12.6 km apart on the US Army Dugway Proving Ground; they are called HiRes one (HR1) and HiRes two (HR2). At each site spherical mirrors with an effective area of $3.7\,\mathrm{m}^2$ concentrate the fluorescence light onto cameras that consist of 256 UV-sensitive photomultiplier tubes (PMT) each. Each PMT observes an angular cone 1° wide. Each mirror covers a patch of sky 16° along the horizon and 14° in elevation. HR1 has 19 mirrors covering elevation angles from 3 to 17°, and HR2 has 42 mirrors

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covering elevations from 3 to 31° above the horizon. Both detector sites aim towards full azimuthal coverage along the horizon. The experiment is specifically designed to allow stereoscopic observation of EAS.

The HR1 site became operational in May of 1997 and is equipped with an older generation of sample and hold electronics. HR2 started data taking in December of 1999 and uses modern Flash-ADC electronics. HiRes stopped taking data in April of 2006, and its equipment is now being integrated into the new Telescope Array Project (TA) in Millard County, Utah, which is a hybrid experiment using fluorescence detectors over a surface array of scintillation counters. TA will start taking data in the beginning of 2008.

2. HiRes measurements of the cosmic ray spectrum

HiRes was designed specifically to allow for stereo observation of CR induced EAS. Stereo observation allows for systematic crosschecks on the atmosphere and provides valuable constraints on geometry. Yet stereo observation is limited to a subset of the available data, and measurements which are statistically imited or, as for example low energy EAS, rely on close proximity to a detector site for detection will always be based on the monocular data sets.

2.1. Monocular cosmic ray observation

Due to the complementary virtues of the two HiRes sites the HiRes monocular data sets cover the widest possible range of energies with substantial overlap between the sets. In that overlap region stereoscopic measurements with hourly measured corrections to the atmospheric database will be used to further reduce the overall systematic uncertainty. Because HR1 started taking data before atmospheric monitoring was implemented at HiRes, monocular data are evaluated using an average atmosphere extracted from the atmospheric data collected during experiment operation. Our 17% over-all systematic uncertainty in the energy scale of the monocular data leads to 31% uncertainty in the monocular CR flux measurements [1].

2.2. Observation of the GZK cutoff

Over many orders of magnitude the CR spectrum follows power law dependencies on energy. Breakpoints in the power laws attact the attention and challenge us to find explanations for their occurrence. Fig. 1(a) shows the HiRes monocular CR spectra. Overlaid with the spectra is a power law fit that has two breakpoints. The lower energy breakpoint marks the so-called ankle in the spectrum, and in the GZK interpretation of the spectrum is produced by e^+e^- production on the CMB. The higher energy breakpoint

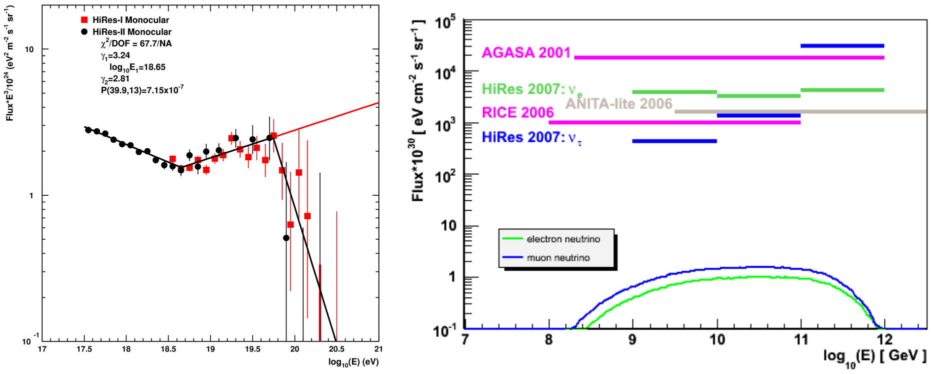

Fig. 1. Left: HiRes monocular spectra with piecewise linear fit. Right: neutrino flux estimates and limits from HiRes.

is exactly at the energy where we would expect it if it was the GZK cutoff. With roughly 5σ significance we can rule out that the power law spectrum found below the expected cutoff continues to beyond 10^{20} eV as suggested by the AGASA experiment.

For the GZK mechanism to work the propagating CR particles need to be protons. Thus one important ingredient to the interpretation of features in the CR spectrum is the chemical composition of the observed flux. The GZK conjecture is based on propagating protons, which at high enough energy can be excited to the Δ^+ resonance in the Cosmic Microwave Background. If the highest energy CR are not protons, the feature we observe in the spectrum is not the GZK cutoff.

The fluorescence technique offers access to composition information through the recorded longitudinal development of the EAS. While there is significant fluctuation between individual EAS, statistical differences exist between samples of proton induced EAS and *e.g.* the showers initiated by Fe nuclei. HiRes measurements reported in [2] indicate that the transition from heavier to lighter composition is finished at about 10^{18} eV and the highest energy CR are mostly protons. We thus conclude that we observed the GZK cutoff at the quoted significance level [3].

3. Cosmogenic neutrinos

The existence of the GZK cutoff requires the existence of cosmogenic neutrinos; neutrinos that appear in the decay of the daughters of the Δ^+ resonance that is at the heart of the GZK mechanism. Using a power law injection model from the assumed astrophysical proton accelerators, we have used fits to our measured monocular spectra to extract an average exponent γ for the injection spectra and an evolution parameter for the source distribution as a function of redshift z. Using the best fit parameters we then proceed to calculate the resulting flux of cosmogenic neutrinos here at earth. Fig. 1(b) shows the neutrino fluxes expected from a fit to the HiRes monocular spectra in comparison with the HiRes neutrino flux limits that were extracted for both electron type and tau neutrinos. Both electron and tau neutrino detection uses the Earth's crust as target, producing either LPM-delayed electromagnetic showers that emerge into the field of view of the HiRes detectors or hadronic showers initiated by tau lepton decays. The limits assume a neutrino spectrum following E^{-2} arriving at earth [4].

4. Conclusions

HiRes has observed the GZK cutoff in the CR spectrum. HiRes composition measurements support this interpretation and provide the motivation for the calculation of cosmogenic neutrino fluxes. No neutrinos were observed in HiRes, leading to new competitive neutrino flux limits.

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